SEISMIC MARGIN ASSESSMENT APPLICATIONS IN ONTARIO NUCLEAR POWER PLANTS

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ABSTRACT

Seismic design of Ontario Power Generation's Pickering A Nuclear Generating Station and Bruce Power's Bruce A Nuclear Generating Station utilised seismic hazard estimates extrapolated from the limited historical record and the prevailing (1965, 1970) National Building Code of Canada's seismic design provisions. Ontario Power Generation (OPG, formerly Ontario Hydro) supported regional seismological and geophysical research to verify seismic hazard estimates used in its operating hydroelectric and nuclear power plants and to comply with evolving requirements for regional and site-specific seismic hazard assessments at new plant sites.

Probabilistic seismic hazard assessments were performed for operating plant sites as the methodology was implemented with eastern Canadian seismic hazard data. The EPRI SQUG seismic margin assessment (SMA) methodology was first utilized in an OPG facility in the late 1980's to establish the seismic capacity of non-safety related piping and equipment adjacent to nuclear safety-related components. Following scoping studies at Pickering A and Canadian regulatory review [1] of the applicability of the SMA methodology to CANDU nuclear power plants, seismic assessment of Pickering A was initiated in 1994. A seismic hazard assessment for the Pickering site using current methodology was completed in 1996. A uniform hazard response spectrum with 0.23g peak ground acceleration formed the basis for seismic capacity/demand evaluations of safety-related systems, structures and components. The SMA walkdown screening procedure was applied, coupled with a relay review and testing program. OPG's seismic assessment report formed the basis for seismic upgrades completed prior to restart of Pickering A Units 1 and 4. The upgrades included anchorage upgrades for shielding and components, strengthening of unreinforced concrete block masonry walls and seismic qualification of replacement equipment.

Bruce Power employed a similar process for seismic assessment and upgrades of Bruce A Units 3 and 4. System consequence evaluations were performed to quantify effects of relay chatter, significantly reducing the quantity of relays requiring seismic evaluation. Units 1 and 2 are currently being assessed and upgraded prior to restart.

Along with other administrative controls on plant design, procurement, operations and maintenance, Bruce A and Pickering A developed Seismic Design Guides and success path equipment lists in order to ensure that the seismic success path is maintained for the life of the facility. The Design Guides document plant-specific requirements for application of the SMA walkdown evaluation, analysis and testing procedures to plant modifications and replacements affecting seismic success path components. EPRI SQUG seismic capability engineer training has been provided for plant engineering staff to aid application of the Design Guides.

SMA evaluations of piping and equipment, cable raceways, trailer-mounted emergency power supplies, switchgear, fuel handling and reactor maintenance equipment have been performed. Many of these evaluations support outage and maintenance activities affecting containment isolations different from those used during normal plant operation.

The SMA methodology has also been used for modifications and operability evaluations in Pickering B and Bruce B (designed using current seismic design practices). EPRI Guidelines for Piping and HVAC systems have been used for evaluations prompted by plant modifications and changes in nuclear safety philosophy. The SMA methodology is being added to the Canadian Standards Association N289.1 Standard scheduled for issue in 2007.

INTRODUCTION

Pickering A and Bruce A Nuclear Generating Stations were designed utilizing seismic hazard estimates extrapolated from the seismological historical record and the prevailing (1965, 1970) National Building Code of Canada's seismic design provisions. Both plants are multi-unit CANDU plants with a common containment system. In addition to the containment envelopes of each reactor unit there is a common pressure relief duct and vacuum building designed to mitigate post-accident pressure increases with a dousing system. On-going geological and seismological research in eastern North America and the application of probabilistic seismic hazard assessment methods to regional seismicity provided seismic hazard information for the plant sites at lower probability of occurrence levels. In order to establish that the plants possessed sufficient seismic capacity at the new seismic hazard levels for the plant sites, Ontario Power Generation (OPG) and Bruce Power initiated seismic evaluations of the plants.

SEISMIC HAZARD ASSESSMENT

In the 1980's, Ontario Power Generation (then Ontario Hydro) supported geological and seismological research efforts aimed at better understanding of postulated seismogenic features and regional seismic hazard. A regional seismic monitoring network operating in southern Ontario supplemented the national network. Probabilistic seismic hazard assessments for Ontario Hydro's nuclear and hydroelectric plant sites were used by Ontario Hydro's Dam Safety Assessment program, for new plant site evaluations and in the 1990's for the Pickering A and Bruce A seismic assessments.

Seismic assessment of Pickering A began in 1993. Probabilistic seismic hazard assessments for the Pickering plant site had been progressively updated as seismological research findings were applied to refining regional hazard models. Data from the strong motion Nahanni and Saguenay earthquakes and several regional earthquakes aided refinement of ground motion and attenuation parameters. In addition, sensitivity to seismic zonation and ground motion relationships was examined. Consensus ground motion parameters developed by the Senior Seismic Hazard Analysis Committee of the U.S. National Academy of Sciences were incorporated. Comparisons were made with regional source models developed by the Geological Survey of Canada for the National Building Code of Canada as well as parameters developed by EPRI's study of Stable Continental Regions.

The USNRC and EPRI seismic hazard studies for central and eastern United States nuclear power plant sites focused significant research attention on seismic hazard issues and provided a model for hazard assessments for the Ontario plant sites. The Atomic Energy Control Board sponsored a seismic hazard workshop to bring together regulatory, utility and research interests. Workshop findings formed the basis for an independent seismic hazard assessment of OPG's Pickering and Darlington nuclear power plant sites. Comparison of the hazard assessments indicated that the review level earthquake response spectrum developed by OPG was an acceptable basis for seismic assessment of Pickering A.

SEISMIC MARGIN ASSESSMENT

A review level earthquake (RLE) for the Pickering site was selected at the 84^{th} percentile, 10^{-4} per annum probability level, described by a uniform hazard response spectrum produced by the seismic hazard assessment. With a zero period acceleration of 0.23g, the RLE is bounded by the EPRI Seismic Qualification Utility Group (SQUG) screening criteria for equipment commonly found in nuclear power plants.

The RLE was defined at the bedrock surface, approximately 18 m below grade. Dynamic properties of the dense glacial till and engineered fill above bedrock at Pickering had been obtained for design of the Pickering B plant in the 1980's. Soil-structure interaction analysis of a single unit reinforced concrete Pickering A reactor building was performed with lower bound, best estimate and upper bound soil dynamic properties. The reinforced concrete Vacuum Building is also pile supported and has similar dynamic response characteristics to the reactor buildings. The Powerhouse structure partially surrounding the reactor unit has a shallow foundation and is structurally independent of the reactor unit. The Powerhouse is a braced structural steel frame structure. RLE in-structure response spectra were generated for evaluation of seismic success path equipment.

A seismic success path of systems, structures and equipment required to safely shutdown, cool, contain and monitor the plant in the event of a major earthquake was defined. Success path systems for Pickering A were chosen to avoid dependence on interconnected seismically qualified systems in the adjacent Pickering B plant (aside from the common containment systems and structures).

The Atomic Energy Control Board (now Canadian Nuclear Safety Commission) had determined that the seismic margin assessment (SMA) methodology [2] was an acceptable means of quantifying seismic capacity for CANDU nuclear power plants [1]. As Pickering A was the first application of SMA to a CANDU nuclear power plant, the initial evaluation, termed the "expert walkdown", was performed by a team of consultants and industry experts with OPG project staff. The purpose of the expert walkdown was to have industry experts experienced with SMA in US and international plants verify the conclusion of Reference [1], as well as to advise OPG on the viability of the preliminary seismic success path. It was determined that Pickering A's structures and equipment were sufficiently similar to U.S. A46 plants that the SMA methodology could be reasonably applied. The expert walkdown also clarified uncertainties in success path definition. For example, it confirmed that the plant Instrument Air system could not be readily screened out due to equipment anchorage issues and susceptibility of tubing to relative displacements between structures. Instead, additional local back-up instrument air supplies for specific success path equipment were identified as required seismic upgrades.

The expert walkdown report formed the basis for detailed walkdowns of success path equipment by EPRI SQUG-trained seismic capability engineers. Equipment anchorage and unreinforced concrete block masonry and shielding walls near success path equpment were the most commonly identified outliers. The Primary Heat Transport system was analysed for loss of coolant accident scenarios as well as the RLE to ensure that seismically initiated loss of coolant conditions were not credible. CANDU-specific components, such as the reactor calandria vessel and on-power fuelling machines, were evaluated using the SMA conservative deterministic failure mechanism analysis method.

With the exception of the pressure relief duct, the reinforced concrete containment structures were screened out as seismically robust. The pressure relief duct at Pickering is an elevated, pier-supported reinforced concrete duct running the length of Pickering A and B, connecting the reactor units to the Vacuum Building. To verify stability of the duct and integrity of the expansion joint seals between duct sections, seismic analysis with simulated ground motion incoherence to model effects of wave propagation along the length of the duct was performed.

Seismic upgrades were performed at Pickering A prior to restart of Units 1 and 4. The upgrades were made in conjunction with extensive refurbishment and replacement of components nearing end-of-service-life dates.

Slightly lower seismic hazard parameters were determined to apply to the Bruce A site. Bruce A is a 4 unit CANDU nuclear power plant with a structural configuration evolved from the Pickering A design. The reactor buildings and Powerhouse share a common massive reinforced concrete foundation founded directly on rock. The pressure relief duct is also at rock surface level within the Powerhouse foundation. Ancillary services buildings are supported directly on rock or on engineered fill above the bedrock. Many of the seismic capability engineers, then employed by EQE Engineering International, who had worked on the seismic assessment at Pickering A, performed the SMA at Bruce A Units 3 and 4. Lessons learned at Pickering A that reduced the work effort at Bruce A included performance of system functionality evaluations to determine the consequences of relay contact chatter. These evaluations identified relays associated with control or power of active electrical components in shutdown systems or relays whose contact chatter could result in the inadvertent actuation of equipment which could prevent safe shutdown.

Instrument rooms at Bruce A with unreinforced concrete block masonry walls were upgraded to meet both seismic and environmental qualification requirements. Light, structural steel braced frame structures housing the standby generators required bracing upgrades as well as strengthening of unreinforced concrete block masonry walls adjacent to electrical and control equipment.

Units 1 and 2 at Bruce A are currently being seismically assessed prior to seismic upgrading. While the Units are nominally identical in design, there are equipment manufacturer differences, field-run piping differences, etc., that require walkdown verification of success path integrity in each Unit.

CONCLUSIONS

The SMA methodology has been shown to be applicable to seismic evaluation of CANDU nuclear power plants. The methodology has been integrated into plant design engineering procedures.

Along with other administrative controls on plant design, procurement, operations and maintenance, Bruce A an Pickering A developed Seismic Design Guides and success path equipment lists in order to ensure that the seismi success path is maintained for the life of the facility. The Design Guides document plant-specific requirements fc application of the SMA walkdown evaluation, analysis and testing procedures to plant modifications an replacements affecting seismic success path components. EPRI SQUG seismic capability engineer training has bee provided for plant engineering staff to aid application of the Design Guides. The SMA walkdown screening an analytical evaluation methods are effective means of seismic qualification of both existing and new plant equipmen

REFERENCES

[1] Ghobarah, A., Heidebrecht, A.C. and Tso, W.K., "Pickering Seismic Safety Margin – Methodology", *AEC Project No. 2.209.1 (INFO-0419)*, Ottawa, Canada, June 1992.

[2] Jack R. Benjamin and Associates Inc., RPK Structural Mechanics Consulting, Pickard, Lowe and Garrick, I.M Idriss and Southern Company Services Inc., "*A Methodology for Assessment of Nuclear Power Plant Seism Margin*", EPRI NP-6041, Palo Alto, CA, October 1988.